International Journal of Electronics,
Communication & Instrumentation Engineering
Research and Development (IJECIERD)
ISSN(P): 2249-684X; ISSN(E): 2249-7951
Vol. 5, Issue 1, Feb 2015, 19-26

ANN BASED OPTIMAL DESIGN OF MICROWAVE FILTER

MANIDIPA NATH

AIACTR, Delhi, India

ABSTRACT

In this work synthesis and optimization of a band-pass filter using coupled resonators elements in end coupled configuration has been realized using suspended strip-line medium. The theoretical design to compute physical dimensions of the resonator elements of the SSL BPF is done using spectral domain technique. The verifications of the frequency dependent S parameters of the overall filter are done using EM simulation. The physical dimensions of resonator elements are optimized for broad operation bandwidth of the filter using ANN-GA optimization techniques. Finally the optimized filter has been fabricated and measured to verify the design approach. It has been observed that the fabricated SSL filter has a wide pass band and significant low VSWR over the frequency band of design. The filter is made ultra wideband and manufacturing tolerances is made flexible with offset coupled strip elements which are an additional advantage of this filter.

KEYWORDS: ANN Based Optimal Design, SSL BPF, EM, ANN-GA, VSWR

1. INTRODUCTION

ANN techniques have been recognized as a powerful tool for microwave design and modeling problems. ANN technique is can be applied to model multidimensional nonlinear relationships and is widely used for microwave filter analysis and synthesis. ANN technique [1-7] is a useful alternative for device modeling where a mathematical model is not available or repetitive electromagnetic (EM) simulation is required. Development of a trained ANN model of a device under concern over a frequency band is very useful to compute frequency response of the same and can replace repetitive EM simulation process where a simple change in the physical dimension requires a complete re-simulation of the structure of the device.

ANN technique can also reduce the cost of computation significantly and thus can produce fast and accurate result compared to the conventional electromagnetic (EM) methods. It helps to improve the speed and accuracy of filter design for communication circuit and systems.

ANN and optimization methods can be combined to get for faster and accurate filter solution. Here genetic algorithm (GA) has been applied for optimization of BW of suspended strip line filter [8-10].

The resonators of the SSL filter are a coupled transmission lines in non homogeneous medium which offer wide bandwidth, tight coupling (3 dB) and low attenuation. This type of structure [11-13] is very useful for microwave & millimeter wave integrated circuits using planar circuit technologies as Mixers, Oscillators, Multiplier, Filters, and Couplers etc.

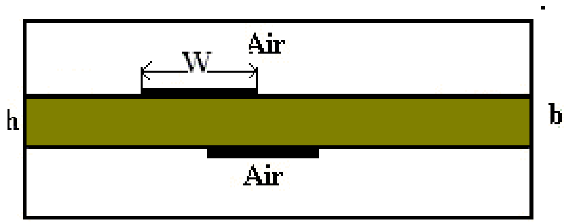


Figure 1: 2D View of the SSL Transmission Medium

2. THEORY

Here a computation method based on quasi-static spectral domain technique [14] has been developed to compute physical dimensions of broadside-coupled suspended stripline resonator elements according to the inter resonator coupling. The basic parameters of the coupled suspended stripline configuration which are required to be calculated are strip capacitance per unit length, mode characteristic impedance, coupling coefficient and modal phase velocities. Finally the coupled resonator elements are utilized to design a SSL filter required to have broad bandwidth. Fundamental resonator elements of the filter are conducting strip elements on both sides of a dielectric substrate in an unsymmetrical configuration with an offset between the strips as shown in Figure 1. To characterise these resonator elements a detail analysis is done using a popular and widely used numerical technique called spectral domain approach (SDA) [14]. Due to asymmetrically located strips there exist c and pi propagating modes corresponding to equal and opposite potential excitations. The advantage of the asymmetrically coupled structure over its symmetrical counterpart is enhanced degrees of freedom in design and less fabrication tolerance. There are few reported results [14] where efforts have been made to analyse this structure using SDA. Here Galerkin's method is used to yield a homogeneous system of equations to determine the propagation constant and the amplitude of current distributions from which the modal characteristic impedances are derived. The solutions corresponding to a basis function that incorporates the physical nature of the mode and leads to easy formulation in the form of pair of algebraic equations with significant analytical pre-processing. However SDA assumes infinite thickness and conductivity of the strip conductor and no discontinuity in the substrate in the sideward direction is allowed.

3. ANALYSIS OF THE BROADSIDE-COUPLED STRIPS

The cross section of the broadside-offset coupled strip lines in a shielded cavity is shown in the figure 1. The structure is assumed to be uniform and infinite in the z direction. The strips are assumed to be infinity thin, perfectly conducting and the dielectric substrates are assumed to be lossless. Due to asymmetry of the structure two-quasi TEM propagating modes(c & π) arising due to in-phase and out of phase potential excitations. The quasi–static SDA is utilized here to evaluate c and π mode capacitance per unit length for the strip elements and consequently mode characteristic impedances and effective dielectric constants are evaluated. Excitation of upper and lower strips with equal (V_1=V_2=1) and opposite (V_1=-V_2=1) potentials the quasi-static capacitances per unit length for the strips can be written as

$$C_{e/o,1} = \frac{a}{2V_1^2}\sum_{k=1}^{K} a_k P_k$$
$$C_{e/o,2} = \frac{a}{2V_2^2}\sum_{k=1}^{K} b_m Q_m \tag{1}$$

The quasi-static per unit length capacitance $C_{p,s}$ of the strips for the mode p=c, π can be computed from [14].

$$C_{p1} = C_{e1} + 0.5(C_{o1} - C_{e1})(1 - R_p) \tag{2}$$

$$C_{p2} = C_{e2} + 0.5(C_{o2} - C_{e2})(1 - R_p^{-1}) \tag{3}$$

Where $R_{c,\pi}$ are the ratios of the voltages on the strips modes c and π and can be evaluated from the even and odd-excitation capacitances per unit length of the strips. Modal characteristic impedances, effective dielectric constants and phase velocities are computed using $C_{p,s}$.

4. SOLUTIONS

Here Galerkin's method is applied to the spectral domain formulation (Equation 3). The basis functions $\tilde{\rho}_1(n)$ & $\tilde{\rho}_2(n)$ are expanded in terms of linear combinations of known set of basis functions.

$$\tilde{\rho}_1(n) = \sum_{k=1}^{K} a_k \tilde{\rho}_k(n)$$
$$\tilde{\rho}_2(n) = \sum_{m=1}^{M} b_m \tilde{\rho}_m(n) \tag{4}$$

Where a_k, k=1, 2 … K and b_m, m=1 …M are unknown coefficients. $\tilde{\rho}_1(n)$ & $\tilde{\rho}_2(n)$ are chosen such that their inverse transform $\rho_k(n)$ & $\rho_m(n)$ are nonzero only over the strips.

The basis functions [5-6] represent the physical characteristics of the charge distribution on the strips which becomes singular on the edges of the strips. This nature is incorporated in the choice of basis functions and convergence is obtained from 2x2 matrix size.

The following basis function are taken for the analysis

$$\rho_1(x) = \frac{1}{W}\left[1 + \left|\frac{2\left(x - S - \frac{W}{2}\right)}{W}\right|^3\right] \tag{5}$$

$$S < x < S + W$$

$\rho_1(x) = 0$ Otherwise

$$\rho_2(x) = \frac{1}{\pi\sqrt{\left(\frac{W}{2}\right)^2 - \left(x - S - \frac{W}{2}\right)^2}} \tag{6}$$

$$S < x < S + W$$

$\rho_2(x) = 0$ Otherwise

5. RESULTS

To validate the method Matlab codes has been generated to analyse the structure under consideration. Variation of the modal characteristic impedance and guide wavelengths for various strip width has been tabulated and compared with the results reported by Kitazawa [15] & Nguyen [16]

The developed analysis has been used to generate numerical results. For an enclosed symmetrical structure c and π mode characteristic impedances are computed and corresponding coupling coefficients are plotted against strip offset positions (εr=2.2, a=2.4, h=0.127).

Table 1: The Range of Input Parameters for ANN

εr	w(mm)	t(mm)	h(mm)	d(mm)
2-10	1.0-5.0	0.2-2.0	0.1-2.5	0.11-1.0

Table 2: The accuracy of Developed ANN

	Effective Permittivities	Characteristic Impedance	Width of Strip(mm)	Length of Strip(mm)
Training	0.1	0.01	0.001	0.0001
Testing	0.1	0.01	0.001	0.0001

6. ANN MODEL

The aim of the training process is to minimize the training error between the target outputs and the actual outputs of the ANNs. Training the ANNs with the use of a learning algorithm is to calculate the effective permittivity, characteristic impedances of suspended stripline, width and length of the strip accurately within a particular frequency band of interest.

Here SSL filter structure has been modeled with ANN and trained with the use of a back propagation learning algorithm for the calculation of width and length of each resonator with different sets of input parameter sets.

ANN outputs are compared to the known outputs of the training data sets and errors are computed. Error derivatives are then calculated and summed up for each weight until all the training data are fed to the network. These error derivatives are then used to update the weights of neurons in the models.

Training proceeds until errors are lower than prescribed values. Currently, there is no deterministic approach that can optimally determine the number of hidden layers and the number of neurons in each hidden layer to achieve a desired accuracy in ANN model. A common practice is to take a trial and error approach which adjusts the hidden layers to strike a balance between memorization and generalization. After several trials, it was found that two hidden layered networks can achieve the task of required high accuracy for suspended stripline filter. The numbers of neurons were 5 for the input layer, 20, 14 for the first, that achieve a desired accuracy in ANN model. A common practice is to take a trial and error approach which adjusts the hidden layers to strike a balance between memorization and generalization.

After several trials, it was found that two hidden layered networks can achieve the task of required high accuracy for suspended stripline filter. The numbers of neurons were 5 for the input layer, 20, 14 for the first, the second hidden layers and 4 for the output layer. The tangent sigmoid activation functions were used in the first hidden layer, logarithmic sigmoid activation functions were used in the first and second hidden layers, respectively. The linear activation function was used in the input and output layers in the neural models for the suspended stripline structure. For the trained ANN

model of the SSL filter under consideration, the inputs are the relative permittivity of substrate materials εr and geometrical dimensions like normalized cavity height, substrate dielectric constant, normalized strip width and the outputs are the effective permittivity (εeff), characteristic impedance ($Z0$), width and length of strips.

The range of input parameters for ANN model of the SSL filter is shown in Table 1. The accuracy of the trained and tested ANN model of the SSL filter is shown in Table 2. The computed coupling coefficients for the resonator sections, width, length of resonator elements has been tabulated in table 3 for the structure under concern.

7. OPTIMIZATION

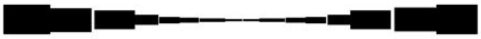
EM simulation is used [Finite Element method (FEM)] for evaluating the response of structure under analysis and an optimization algorithm using GA is used to obtain frequency response of the S parameters of the SSL filter for best performance of the same within the frequency band of design. The optimization process involving trained ANN model and GA optimizer is used for calculating frequency response of the SSL filter. Different learning algorithms have been used to obtain better performance and faster convergence.

To cover the full frequency band from 18.0-40.0 GHz. fifteen resonator sections are separately designed using ANN model and optimization of physical dimension of each resonator section of this filter is done using ANN-GA algorithm.

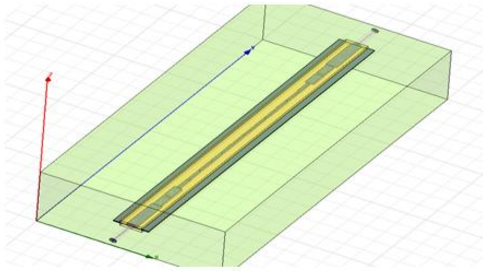
The SSL filter having fifteen sections as shown in Figure 2 is developed where the individual quarter wavelength resonator sections are integrated and capacitive coupled through a gap of 0.2 mm along the length (40.0 mm). The dimensions of the SSL filters for fabrication are shown in Table 4. The effect of inserting 0.2 mm coupling gap between successive resonator sections effectively alters the cut-off frequencies and lowers the operating frequency band slightly. To compensate the effect of the gap capacitance the resonator length is scaled down appropriately. Alternatively the target design frequency may be kept at higher value to maintain the filter response for the desired operating band. The most accurate results can be obtained using this type of structures with a homogeneous dielectric where even and odd mode phase velocities are same.

Table 3: Design Data for 15 Sections SSL Filter

Filter Sections	g Values	Coupling Coefficients	Width of Strips (mm.)	Offset Value in mm.	Length of Strips (in mm.)
1	1.7635	0.6361	0.69	0.109	1.8732
2	1.2791	0.6238	0.59	0.101	1.8740
3	2.6920	0.5426	0.226	0.1	1.8811
4	1.3826	0.5278	0.192	0.102	1.8823
5	2.7654	0.5227	0.18	0.1	1.8827
6	1.3991	0.5204	0.177	0.1	1.8830
7	2,7811	0-.5193	.175	0.1	1.8831
8	1.4024	0.5189	.173	0.1	1.8832



(a)



(b)

Figure 2: 15 Section Suspended Stripline Filter (a) Layout and (b) 3D View

Figure 3: Fabricated SSL Filter

The fitness function F used for GA optimizer for this optimization problem is

$$\text{maximize } F = \sum_{i=1}^{N} w_i f_i \quad \text{where} \quad f_i = \sqrt{\frac{S_{21}desired}{S_{21}calculated}}$$

Finally GA is used to optimize the bandwidth of the SSL filter using the fitness function shown above. The optimal filter structure is simulated using HFSS and Figure 4 shows the simulated response of the filter. The simulated filter pass band shows a 73.3% bandwidth (18.0 GHz - 41.0 GHz) with an insertion loss of 0.5 dB (maximum) over the operating band. The frequency roll off rate is 70 dB / decade.

8. MEASUREMENT

The fabricated SSL filter as shown in Figure 3 is characterized using VNA for measurement of the frequency response of the same. The measured results of the fabricated SSL filter are shown in Figure 5 which shows a broadband BPF over 18.0 GHz- 40.0 GHz frequency band with an average insertion loss of 3.5 dB over the band. The average VSWR over the band is 1.5. Table 5 shows a comparison between simulated and measured performance of the SSL filter. The measured frequency bandwidth is 96.0% in the frequency band from 18.0 GHz - 40.0 GHz. The centre frequency of the developed SSL filter is 30.0 GHz and measured frequency roll off is 60 dB / decade. The measured insertion loss is quite high compared to the simulated value. The discrepancies are coming due to fabrication inaccuracies of the strip elements and practical losses associated with connectors, cables and the filter fabrication process. The loss can further be minimized

using corrective measures. So a broadband filter with low insertion loss and sufficiently miniaturized design optimization has been done using ANN-GA algorithm. The ANN method provides fast and accurate results and reduces the computational costs associated with a time consuming EM solver in the design of microwave filters. These methods can be used in combination with standard filter design methods to design complex microwave filters. It helps to improve the speed and accuracy of filter design for communication circuit and systems.

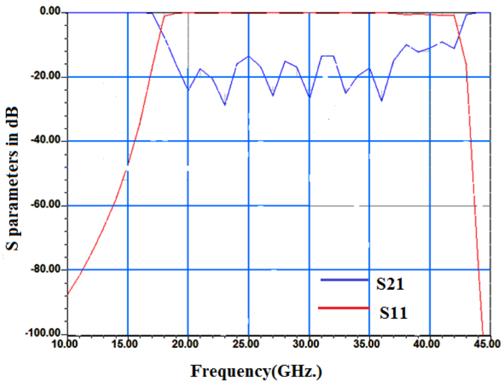


Figure 4: Simulated Result of SSL BPF

Figure 5: SSL BPF Measured Result

Table 4: Optimized Physical Dimension of 15 Section SSL Filter

Filter Sections	Width of Strip (mm.)	Length of Strip (mm.)	Filter Sections	Width of Strip (mm.)	Length of Strip (mm.)
1	W1 = 0.20	L1=1.90	5	W5 = 0.077	L5=1.91
2	W2 = 0.18	L2=1.91	6	W6 = 0.075	L6=1.91
3	W3 = 0.09	L3=1.91	7	W7 = 0.073	L7=1.91
4	W4 = 0.08	L4 =1.91	8	W8 = 0.071	L8=1.91

Table 5: Comparison of Simulated Performance of the Filter and Measured Performance

Filter Parameter	Simulated	Measured
VSWR Bandwidth	23.7 GHz	21.2 GHz
Frequency roll off	70 dB/decade	60 dB/decade
Insertion loss	0.2 dB	3.5dB

REFERENCES

1. Burrascano, P, M. Dionigi, C. Fan celli, and M. Mongiardo, A neural network model for CAD and optimization of microwave filters," *IEEE MTT-S Int. Microwave Symp. Digest*, Vol. 1, 13-16, June 1998. PIERS ONLINE, VOL. 3, NO. 7, 2007 a1134

2. Fedi, G, A. Gaggelli, S. Manetti, and G. Pelosi, A finite-element neural-network approach to Microwave filter design," *Microwave and Optical technology letters*, Vol. 19, 36-38, September1998.
3. Wang, Y, M. Yu, H. Kabir, and Q. J. Zhang, Effective design of waveguide dual mode filte using neural networks," *IEEE MTT-S Int. Microwave Symposyum*, San Francisco, USA, June 2006.
4. Li, X, J. Gao, J. Yook, and X. Chen, Bandpass filter design by artificial neural network modeling," *Proceedings of APMC*, 2005.
5. Watson, P. M, C. Cho, and K. C. Gupta, Electromagnetic-Artificial neural network model for synthesis of physical dimensions for multilayer asymmetric coupled transmission structures, "*Int. Journal of RF and Microwave CAE*, Vol. 9, 175-186, May 1999.
6. Gunez, F. and N. Turker, Artificial neural networks in their simplest forms for analysis and synthesis of RF/Microwave planar transmission lines," *Int. Journal of RF and Microwave CAE*, Vol. 15, No. 6, 587-600, November 2005.
7. Banciu, M. G, E. Ambikairajah, and R. Ramer, Microstrip filter design using fdtd and neural networks," *Microwave and Optical Technology Letters*, Vol. 34, No. 3, 219-224, August 2002.
8. Dougherty, R. M, “mm-wave fillter design with suspended stripline," Microwave Journal, pp.75-84, Jul. 1986.
9. Christopher Ian Mobbs, John David Rhodes, “A Generalized Chebyshev Suspended Substrate Stripline Band pass Filter,” IEEE transactions on Microwave Theory and Tech, vol. 31, No.5, pp. 397-402, May 1983.
10. Wolfgang Menzel1, Mohammad S. Rahman Tito1, Lei Zhu2, “Low-Loss Ultra-Wideband (UWB) Filters Using Suspended Stripline” Proceeding IEEE APMC 2005.
11. Sturdivant, R, “A capacitively coupled BPF design using a suspended substrate stripline,"Microwave Journal, pp.71-76, Nov. 1993.
12. M. Chen, C.-Y. Jiang, W.-Q. Xu, M.-H. Ho, “Design of high order suspended stripline, Progress In Electromagnetics Research Letters, Vol. 8, 9–17, 2009.
13. Lin, L.-J, M.-H. Ho, and W.-Q. Xu, “Design of compact suspended stripline bandpass filters with wide stopband”, Microwave and Optical Technology Letters, Vol. 50, No. 4, 865–868, Apr. 2008.
14. T. Itoh, A. S. Herbert, “A Generalized Spectral domain analysis for coupled suspended microstripline with tuning septum” IEEE Tran. MTT-26, No.10 October 1978.
15. T. Kitazawa, H. Kumagami, Y. Hayashi, “Unsymmetrical broadside-coupled stripline” Electronics Letters, May 1982 Vol-18 No.10.
16. C Nguyen and Kai Chang “Design and Performance of Millimer-wave end–coupled band pass filters” International Journal of Infrared and Millimetre Wave, Vol. 6 No 7, 1985.